Analysis Of Similar Earthquakes In Seismic Gaps

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Final Technical Report

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Technical Abstract

A large but conflicting literature exists which suggests that the seismic propagation properties of the Earth in seismogenic areas may be temporally variable and could be correlated with the nucleation times of moderate to large earthquakes. During this project, methods of identifying the best natural sources for addressing this problem and new analysis techniques were developed and applied to obtain bounds on allowed temporal variability of seismic parameters. Work included the comprehensive identification of microearthquakes producing similar seismic wavefields in large digital data sets and the use of these sources in the analysis of shear-wave splitting, wave velocity, and seismic coda. A related project also used earthquake cluster catalogs obtained under NEHRP support to obtain a new small-scale stress map of the Anza region and corresponding insight into the mechanical forces currently operating there. Conclusions are pessimistic for earthquake prediction, in that no evidence was seen for precursory changes in two seismically active regions of the San Andreas fault system with high seismic hazard. However, it is also clear that the present resolution of the measurements still allows small precursory changes and that the ongoing improvement in data quality will allow future estimates to be made at even higher resolution to continue to address the crucial issue of whether or not earthquakes have identifiable precursors. Analysis of the Landers mainshock region, which ruptured during this project, is ongoing under current NEHRP support.

Non-technical Abstract

Evidence for systematic changes in otherwise nearly identical microearthquake seismograms was evaluated. Such variations, if detectable, would provide evidence for physical changes in and adjacent

to active fault zones, with corresponding applications towards earthquake prediction. Although the study was sensitive to previously unattainable levels of resolution, no such effects were detected. However, this project was also instrumental in obtaining a new high-resolution regional map of stresses in the Anza seismic gap in southern California, and is presently being used in an ongoing study of the 1992 Landers earthquake region, which produced the largest earthquake in California during the past 50 years.

Summary of Results from this Project

Aster and Scott (1993) published a summary of useful applications for similar earthquakes which included a widely-used algorithm for unbiased characterization of wavefield similarity in large digital microearthquake data sets based on median network crosscorrelation maxima. A three-component digital data set spanning 10 years recorded the Anza seismic gap was used as an example and served as a data set for several subsequent publications.

Hartse et al. (1994) (co-sponsored by Los Alamos/IGPP award number 324) utilized focal mechanism inversions to reveal significant lateral variations in stress orientations along the Anza segment of the San Jacinto fault zone, The most notable stress anomaly is within the 20 km aseismic (seismic gap) portion of the fault zone σ_1, where the maximum-compressive stress is nearly horizontal and is oriented at 74° ±13° relative to the fault strike. This contrasts with orientations ranging from 62° ± 11° to 49°± 7° along the more seismically active portions of the fault zone immediately to the northwest and southeast of the seismic gap. Approximately 15 km west of the seismic gap, in the off-fault Cahuilla swarm area, σ_1 and σ_3 solutions are rotated clockwise by about 25° relative to the regional stress model of σ_1 horizontal and trending north-south and σ_3 horizontal and trending east-west. Roughly 10 km southeast of the seismic gap near the Buck Ridge fault, σ_1 and σ_3 are rotated counter-clockwise by about 10° relative to the regional solution. Northwest of the seismic gap, along the fault zone, σ_3 plunges about 30° from the horizontal, correlating with a local increase in reverse faulting between the Hot Springs and San Jacinto faults. Southeast of the seismic gap, σ_1 plunges about 45° from the horizontal, correlating with a local increase in normal faulting in the trifurcation region of the Buck Ridge, Clark and Coyote Creek faults.We propose a simple mechanical model in which a block rotation superimposed on the dominant right-lateral strike-slip motion of the fault zone satisfies the first-order observations of stress orientation, faulting, and horizontal surface strain. Under this model the Anza seismic gap is the region of zero convergence between the northeast and southwest sides of the fault, and the fault zone strength within the seismic gap is either comparable or exceeds fault zone strength adjacent to the gap.

Scott et al. (1995) used similar earthquake pairs recorded by the Anza Seismic Network as repeatable sources to place an upper limit on temporal changes in seismic velocity in the vicinity of the Anza seismic gap during a 10 year period from 1982 - 1992. Relative arrival times for each pair of events were found using a cross-correlation method and relative locations were calculated to verify that the pairs have nearly identical hypocenters. Temporal separation between events in these pairs varied from less than 1 d to almost 7 y. It was determined that the long-term changes in seismic travel times, as measured from the pairs with the longest temporal separations, were not significantly greater than the noise level estimated from the short-time-separation event pairs. Almost all P-wave paths showed less than 0.06% (0.007 s) change in travel time and all S-wave paths showed less than 0.03% (0.004 s) change. Sensitivity tests placed an upper bound on travel-time changes that could be compensated

by hypocenter mislocation at 0.2%. There was thus no evidence found to support the hypothesis that localized stress accumulation is causing measurable seismic changes in seismic velocity in the Anza region.

Aster et al. (1996) (in press; expected publication date: April, 1996) summarized the large but conflicting literature which exists suggesting that the scattering properties of the Earth in seismogenic areas may be temporally variable and that this variability could be correlated with the nucleation times of moderate to large earthquakes. To search for temporal variations in coda Q in the vicinity of an expected moderate earthquake nucleation region along the San Jacinto fault zone, pairs and clusters of earthquakes recorded by the Anza Seismic Network between 1982 and 1992 were examined. To minimize differences arising from path and source variability, only the most similar examples of microearthquake wavefields were intercompared. To assess coda Q differences between similar microearthquake signals, a search was performed for systematic temporal changes in moving-window spectral amplitude ratios. Coda variation attributable to source differences produces a spectral ratio term which is constant with respect to seismogram time and thus can be discriminated from temporal change in the Earth response. For a single-scattering coda model with an envelope decay function of the form $t^{-m}e^{-\pi f t/Q}$, the relationship between the natural log amplitude spectral ratio and $\Delta Q^{-1} = Q_{c2}^{-1} - Q_{c1}^{-1}$ is linear, i.e., $\ln r(f,\ t) = \boldsymbol{p} f t \boldsymbol{D} Q^{-1}(f) + W(f)$, where W(f) is a time-independent relative source term. To obtain robust uncertainty estimates $Q^{-1}(f)$ and $W(f)$, we utilized multitaper spectral analysis coupled with a non-parametric Monte Carlo confidence interval estimation procedure. For the most similar events in the Anza region (coda crosscorrelation values of approximately 0.7 for 16 s of coda), it was found that coda Q as a function of time was stable at a typical 1σ resolution of only between -25% and +50% of the reference coda Q value for the area, even in the best-constrained frequency bands. Comparison of similar microearthquake coda signals with both short and long temporal separations indicated that all of this variability can be reasonably attributed to random fluctuations in the coda which are driven by source variability and was not indicative of any systematic temporal variability in coda Q. To obtain estimates of relative coda Q that are more precise than this level, the spectral ratio analysis technique requires significantly more similar earthquakes than are produced by seismogenic processes in the Anza region. Such earthquakes have been observed to occur in other regions of the San Andreas Fault system and were analyzed in Antolik et al. (see below).

Antolik et al. (1996) (accepted for publication, expected publication date: April, 1996) noted that nearly two-thirds of the microseismicity occurring at Parkfield, California consists of repeating clusters of closely located events exhibiting waveform crosscorrelation values exceeding 0.95. This observation, coupled with a very high probability for a M≈ 6 earthquake within the next decade, make this segment of the San Andreas fault system a prime location to search for temporal variations in coda Q associated with crustal changes which may occur during the earthquake cycle. The coda comparison analysis method described in Part 1 of this study (*Aster et al*., 1996; summarized above) was applied to data from four borehole stations of the Parkfield High Resolution Seismic Network for the period January, 1987 through February, 1994. We examined 21 of the nearly 300 repeating clusters observed to date. The restriction of the data set to only the most highly similar sources was observed to be critical; small differences in source processes, even for event pairs with centroid locations within approximately 20 m, significantly increased the spurious noise level in the parameter estimates. Absolute 68% confidence bound estimates obtained on the repeatability of coda Q for all microearthquake pairs were ±10% for frequencies below 20 Hz. Tighter constraints are obtainable by

reconstructing the temporal history of coda Q from the first difference measurements between microearthquake pairs. These functional reconstructions showed that the mean value of coda Q did not vary by more than approximately 5% from 3-30 Hz at the 1σ level during the study period. However other observables, such as an increased level of microseismicity, suggest that a preparatory stage for the next Parkfield earthquake has begun, indicating that coda Q is so far showing no signs of sensitivity to preparatory processes at Parkfield.

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